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SOME UNIQUE DESIGNS OF MICROWAVE FERRITE PHASE SHIFTERS

H. Jones
F. Reggia

30 December 1963

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H. Jones
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FOR THE COMMANDER:
Approved by

John W. Seaton, for
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Chief, Laboratory 200

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ILLUSTRATIONS

ABSTRACT

Several unique types of microwave ferrite phase-shifter designs are described. Each type offers certain distinct advantages when used in the laboratory and in microwave systems. The most salient feature of these low-loss devices is the design compactness, consistent with optimum electrical performance.

The electrical characteristics of these phase shifters and their components are given. These characteristics show that as much as 500 deg of phase shift can be achieved in X-band with a one-in. spacing between input and output ports. In each case, only a small magnetic field strength is required to obtain the desired phase shift.

Other features of these ferrite devices include simplicity in construction, low cost, and small physical size.

1. INTRODUCTION

Reciprocal ferrite phase modulators designed in rectangular waveguide, making use of small longitudinal, magnetic control fields, were first extensively developed at these laboratories by Reggia and Spencer (ref 1). Since that time, this technique has been successfully used at frequencies from 3.0 to 30.0 Gc with good results. Although only a few notable changes have been made in the basic design, improvements to enhance the power handling capabilities have been realized through the use of ridge-waveguide techniques.

In the development of the more sophisticated radar systems, phase shifters are finding increasingly wider usage. In many applications, phase shifters having unusual configurations and extreme compactness with no deterioration in electrical performance are needed. To meet these requirements, some new ideas were exploited, and advances in the microwave art were utilized. Some of the resulting designs are described in this report.

2. DESIGN TYPES AND DESCRIPTIONS

Cross-sectional views of several ferrite phase modulators for 3-cm wavelength making use of the techniques originally described in reference 1 are shown in figure 1. They consist essentially of a longitudinally magnetized ferrite rod centrally located inside a rectangular waveguide excited in the TE_{01} mode. These devices differ only in the method used to get the microwave energy and magnetic control field into the ferrite rod. In each case, the high dielectric constant (13.6) of the ferrite is used to concentrate the microwave energy; the variable permeability with applied magnetic field is used to obtain the desired phase shift.

The ferrite rod used as the phase-shifting element consists of a low-loss MgMn ferrite (ref 2); its useful range of diameters for the

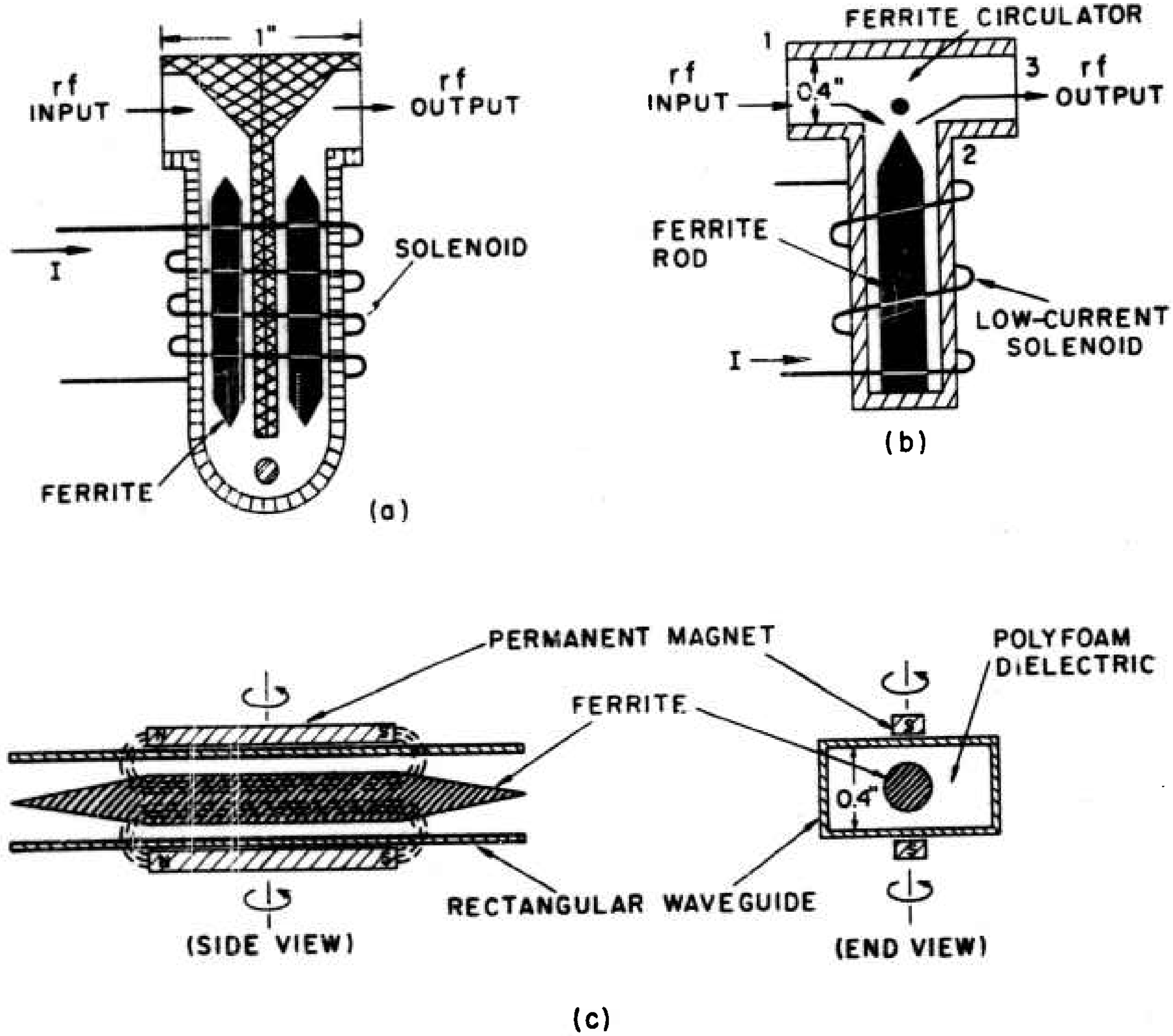

Figure 1. Simplified sketches of microwave ferrite phase modulators.

9- to 10-Gc frequency region is from 0.250 to 0.300 in. Impedance matching was accomplished by using linear tapers at both ends of the ferrite rod and polyfoam dielectric support.

The series-doublet type of phase modulator shown in figure 1a consists of two 90-deg E-plane bends, two series-connected transmission-type phase modulators joined together with a 180-deg zero-radius bend (ref 3). A low-current solenoid is used to supply a longitudinal magnetic control field. The total distance between the input and output ports of the complete assembly is 1 in. This construction provides a compact assembly; its design is characterized by low insertion loss, large phase-shift capability, and low input VSWR.

The T-circulator type of phase modulator shown in figure 1b consists of a small T-type E-plane circulator (ref 4) (1 1/4 by 1 1/4 in.) and a short reflection-type phase modulator (ref 5) connected to port 2. Microwave energy enters port 1 of the circulator and leaves port 2 where it enters the ferrite phase modulator. This microwave energy experiences a phase shift in passing through the magnetized ferrite rod to the short circuit end of the waveguide where it is reflected and experiences a second phase shift in passing back through the ferrite rod, finally leaving port 3 of the circulator. Since the microwave energy enters and leaves the same port of the phase modulator section, the length of the ferrite rod (with only one impedance matching taper) need be only one half that required by an equivalent transmission-type phase modulator. This T-circulator type phase modulator assembly is characterized by the short distance between input and output ports, a small transverse length, very large phase shifts, and compactness for the entire waveguide assembly.

The magneto-mechanical type of phase modulator shown in figure 1c is identical to the original design described in reference 1 except for the rotating magnets at the top and bottom of the waveguide. These magnets are used to supply the longitudinal, magnetic control field. For this type of reciprocal phase modulator, a strong magnetic field applied perpendicular to the axis of the ferrite rod has little or no effect on the propagation of microwave energy through the ferrite rod. However, when the small permanent magnets are rotated to a position parallel to the ferrite rod (fig. 1c, side view) and their magnetic fields are such that they oppose each other, the resultant longitudinal field between the two magnets causes a maximum phase shift of the microwave energy in passing through the ferrite rod. Thus, a simple 90-deg rotation of the permanent magnets can produce a large reciprocal phase shift of the microwave energy. This type of fixed-tuned phase shifter is characterized by its simplicity, light weight, no external electrical power requirements, low insertion loss, and a large phase-shift capability.

All three of the above phase-modulated types, to be described in detail later, were designed in standard rectangular waveguide (0.400 by 0.900 in. i.d.). A polyfoam dielectric material was used in each case

to support the ferrite-rod phase-shifting element in the waveguide.

3. EVALUATION AND PERFORMANCE ANALYSIS

3.1 Component Evaluation

Two very useful waveguide components that are vital to the design of the series-doublet phase shifter are the 90-deg single-mitered E-plane bend and the 180-deg zero-radius E-plane bend (ref 3). Aside from their prominence in this application, these bends have rendered feasible certain other waveguide devices such as antennas and RF system designs. The input VSWR as a function of frequency for these components are shown in figure 2. Here, it is seen that the VSWR for each of these components is 1.06 or less over a 10-percent bandwidth. The VSWR characteristics of the composite assembly (unloaded) are given in the top curve of the same figure, which shows the values to be less than 1.10 over a 15-percent bandwidth. With this kind of performance and compactness (input-to-output port, 1 in. maximum) it was evident that a ferrite-loaded phase shifter could be conceived utilizing the folded waveguide structure shown in the inset of figure 2.

3.2 Series-Doublet Modulator

The phase-shift and input-VSWR characteristics of the series-doublet phase modulator versus applied magnetic field strength are shown in figure 3. These results were obtained with two tapered ferrite rods (0.274 in. diameter) at 9.6 and 9.7 Gc. The total length of these rods was 2 1/8 in. including the 3/4-in. impedance-matching tapers at both ends.

The low-current solenoid supplying the magnetic control field consisted of 2440 turns of No. 30 wire wound around the 1- by 1-in. double rectangular waveguide section. The total length of the solenoid was 1 5/8 in., and its normal operating currents were from 0 to 300 ma, corresponding to a magnetic field strength of 0 to 450 amp turns/in.

As seen in figure 3, phase shifts in excess of 500 deg are possible in the 1-in. distance between the input and output ports. The input VSWR of this modulator, shown at the bottom of this figure, remained below 1.40 for all values of applied field. The zero-field insertion loss was 0.3 db, and the amplitude modulation observed at the output was no greater than ±0.2 db. The solenoid current required to obtain the necessary magnetic field strength is also shown at the top of this figure.

3.3 Reflection Modulator

In order to take advantage of the very compact design of the reflection-type phase modulator (ref 5), it was desirable to use a very small ferrite circulator to couple in and out of its single waveguide port.

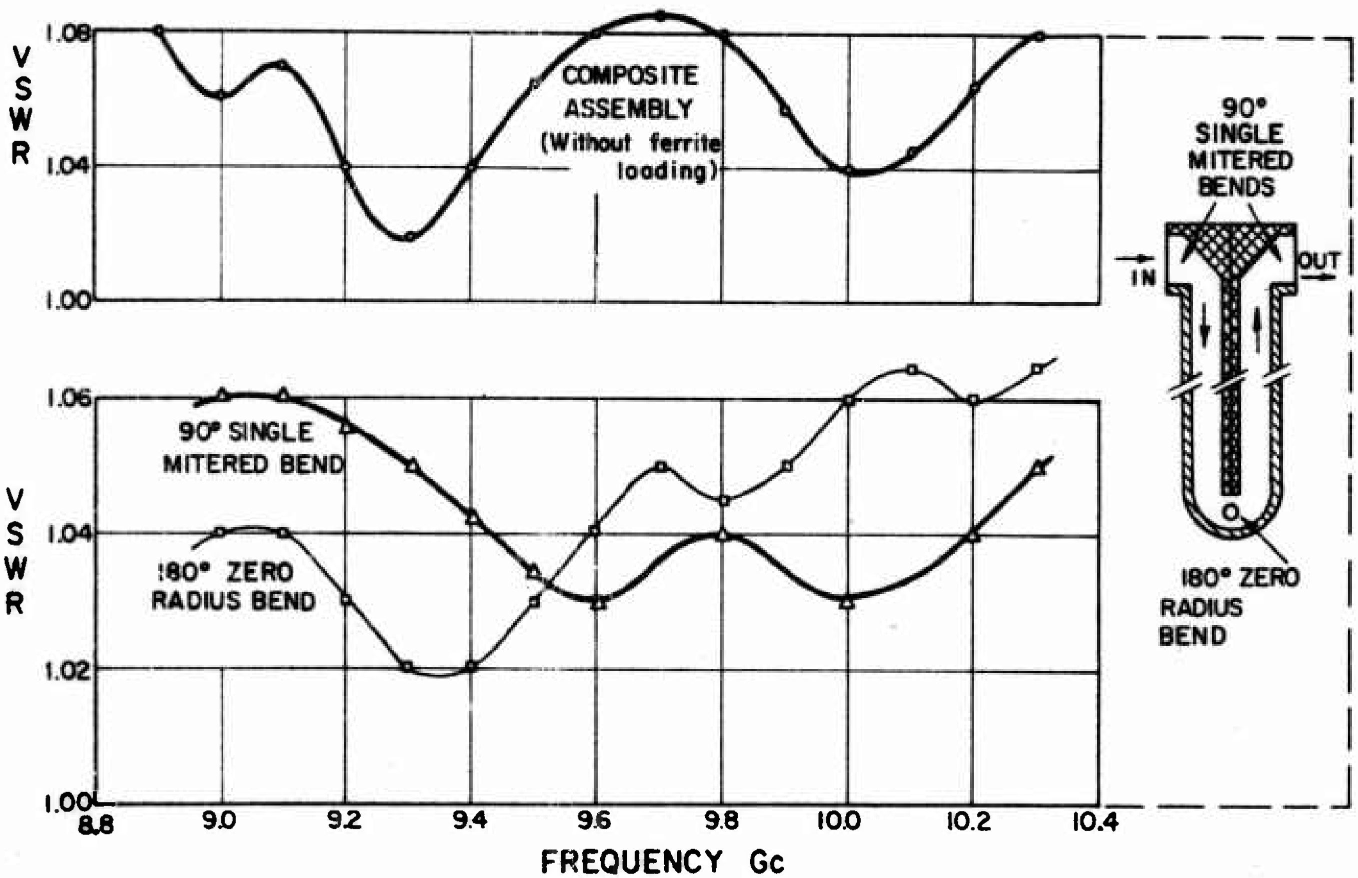

Figure 2. Input VSWR versus frequency of individual components and composite unloaded waveguide assembly. Change of scale in the ordinate should be note .

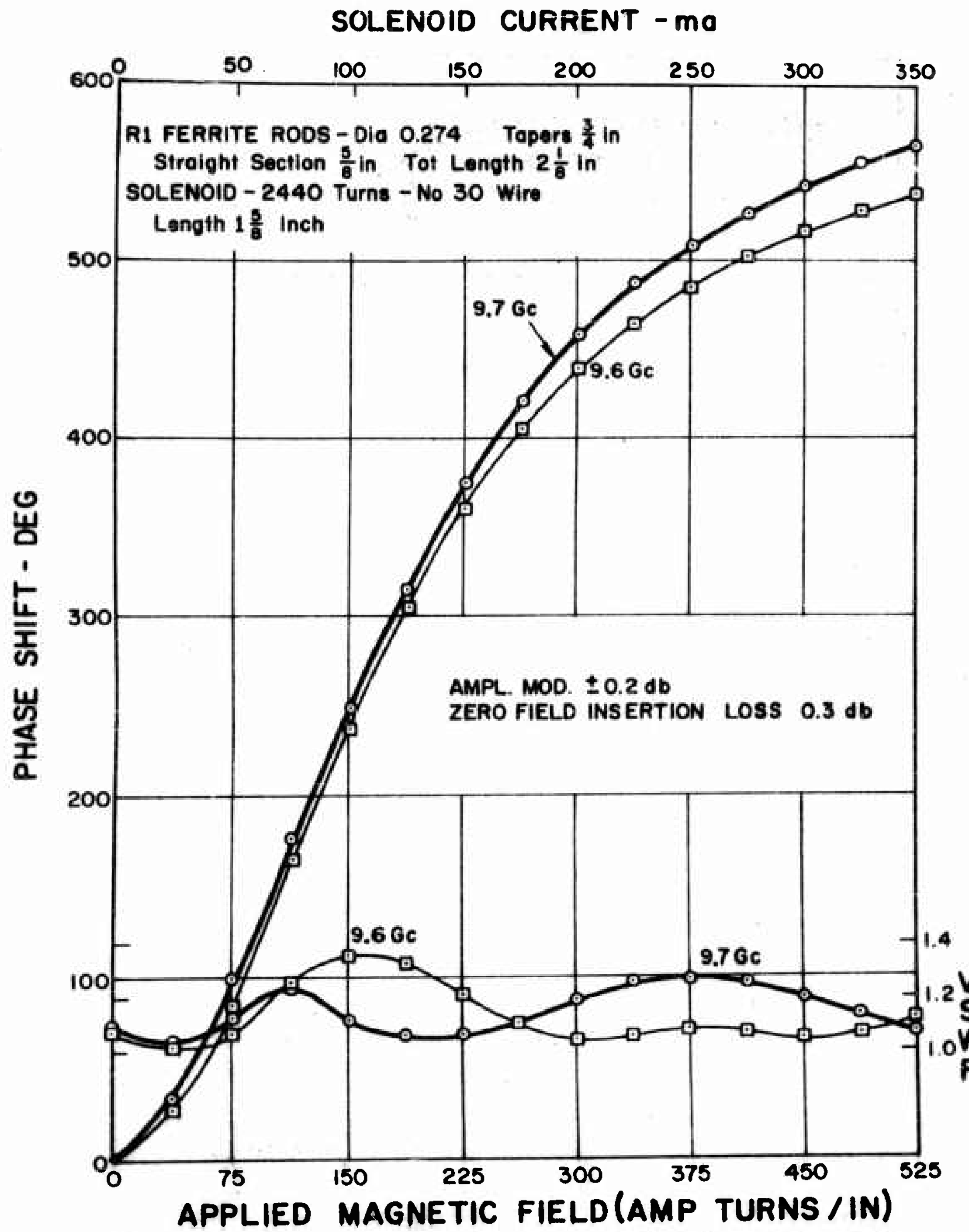

Figure 3. Electrical characteristics of series-doublet phase modulator.

The electrical characteristics of this E-plane tee circulator (ref 4) as a function of its operating frequency are shown in figure 4. Although this model resulted in only narrow-band operation, it should be possible to design models to operate over a much broader frequency range. The physical dimensions of this circulator, along with the identity of its 3 ports, are given at the top of this figure.

As seen in figure 4, an operating bandwidth of 75 Mc (9.275 to 9.350 Gc) resulted in an input VSWR of less than 1.3, an isolation in the reverse direction of circulation of greater than 20 db, and an insertion loss in the forward direction of less than 0.3 db over the same bandwidth. The input VSWR of the load termination and power detector used for these measurements was less than 1.05.

The phase-shift characteristics of this reflection-type phase modulator at 9.325 Gc versus applied magnetic field is shown in figure 5. The diameter of the ferrite rod used for these measurements was 0.275 in., and its total length was 1 3/4 in. including its single 3/4-in. impedance-matching taper.

As seen in figure 5, phase shifts in excess of 500 deg are possible with a magnetic field strength of 340 amp turns/in. The solenoid current required to obtain the necessary magnetic field strength is also shown at the top of this figure. The low-current solenoid, wound around the 1/2- by 1-in. waveguide section, was 7/8 in. long and consisted of 3760 turns of No. 37 wire. The zero-field insertion loss of this modulator assembly was approximately 0.5 db, and the amplitude modulation measured at its output was no greater than 0.2 db. The measured input VSWR for this compact phase modulator was less than 1.20.

3.4 Magneto-Mechanical Modulator

When designing compact waveguide assemblies, it is often desirable to have small reciprocal phase shifters that do not require electrical control power for their operation but that can be fixed-tuned to any desired phase shift. Such a modulator, the magneto-mechanical type, has been developed. It uses a simple mechanical arrangement to change the direction of the magnetic control field instead of its magnitude as was done in the technique originally described in reference 1.

A simplified sketch of a magneto-mechanical phase modulator is shown in figure 1c, and the electrical characteristics of the first constructed model versus the angle of rotation of the permanent bias magnets are given in figure 6. These measurements were obtained at 9,700 Gc with a MgMn ferrite rod having a diameter of 0.270 in. and a total length (including two impedance-matching tapers) of 2 5/8 in. Two small rotatable Alnico permanent magnets (1/4 by 1/8 by 1 1/4 in.) were used, above and below the ferrite loaded waveguide, to obtain the necessary longitudinal magnetic control field.

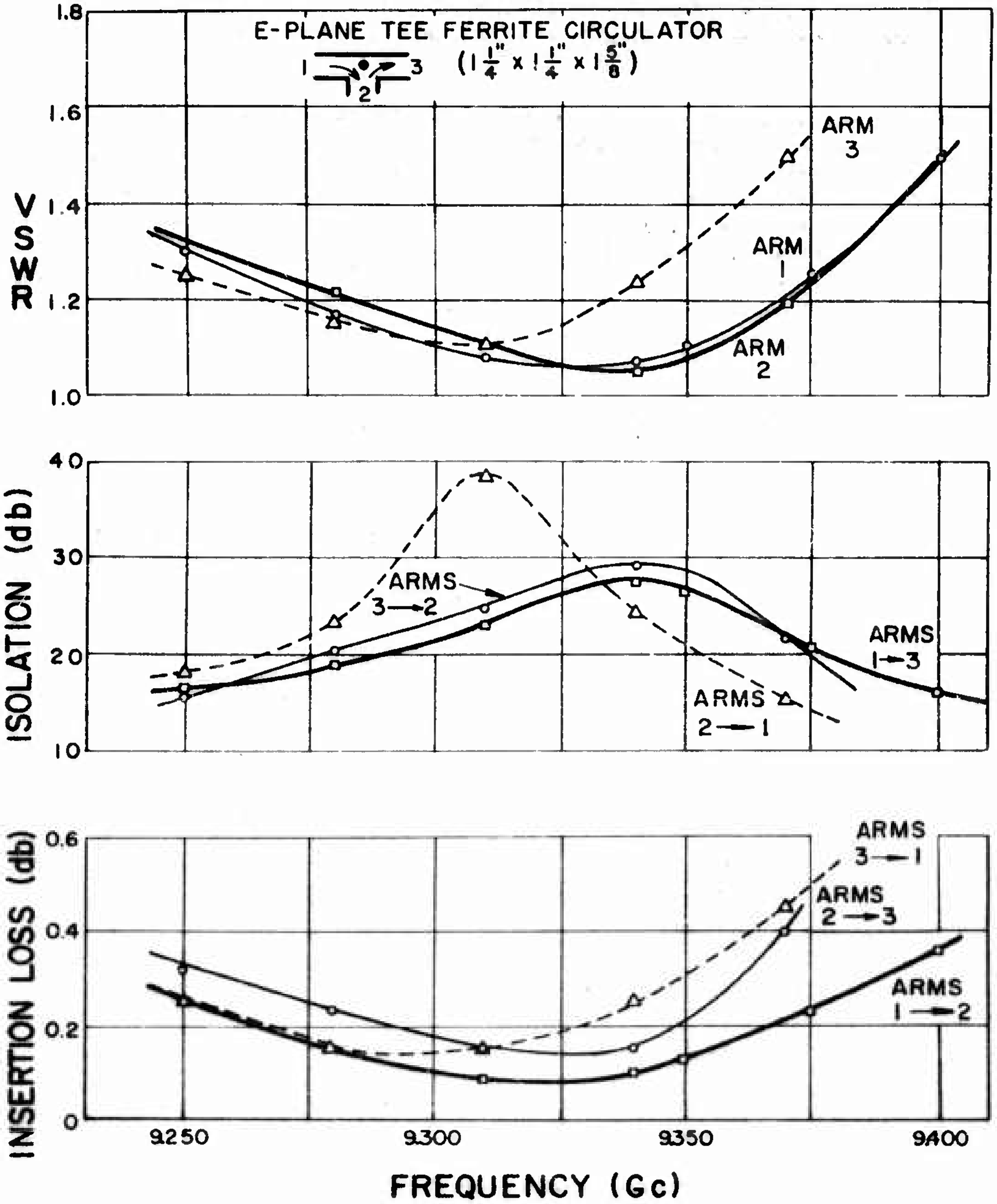

Figure 4. Electrical characteristics versus frequency of E-Plane tee-type of ferrite circulator. Input VSWR of load termination and power detector was less than 1.05 at 9.325 Gc.

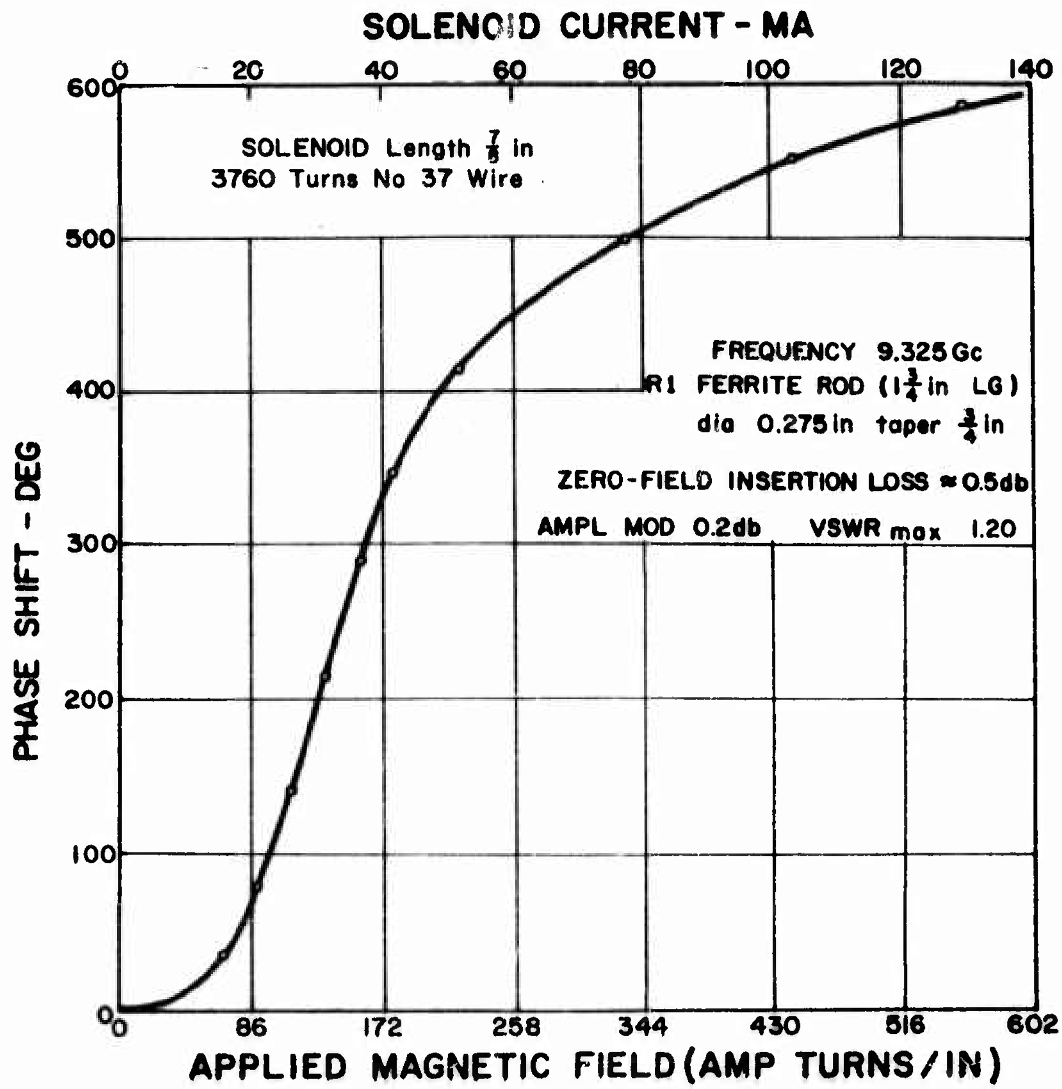

Figure 5. Phase shift versus applied magnetic field of reflection-type ferrite phase modulator.

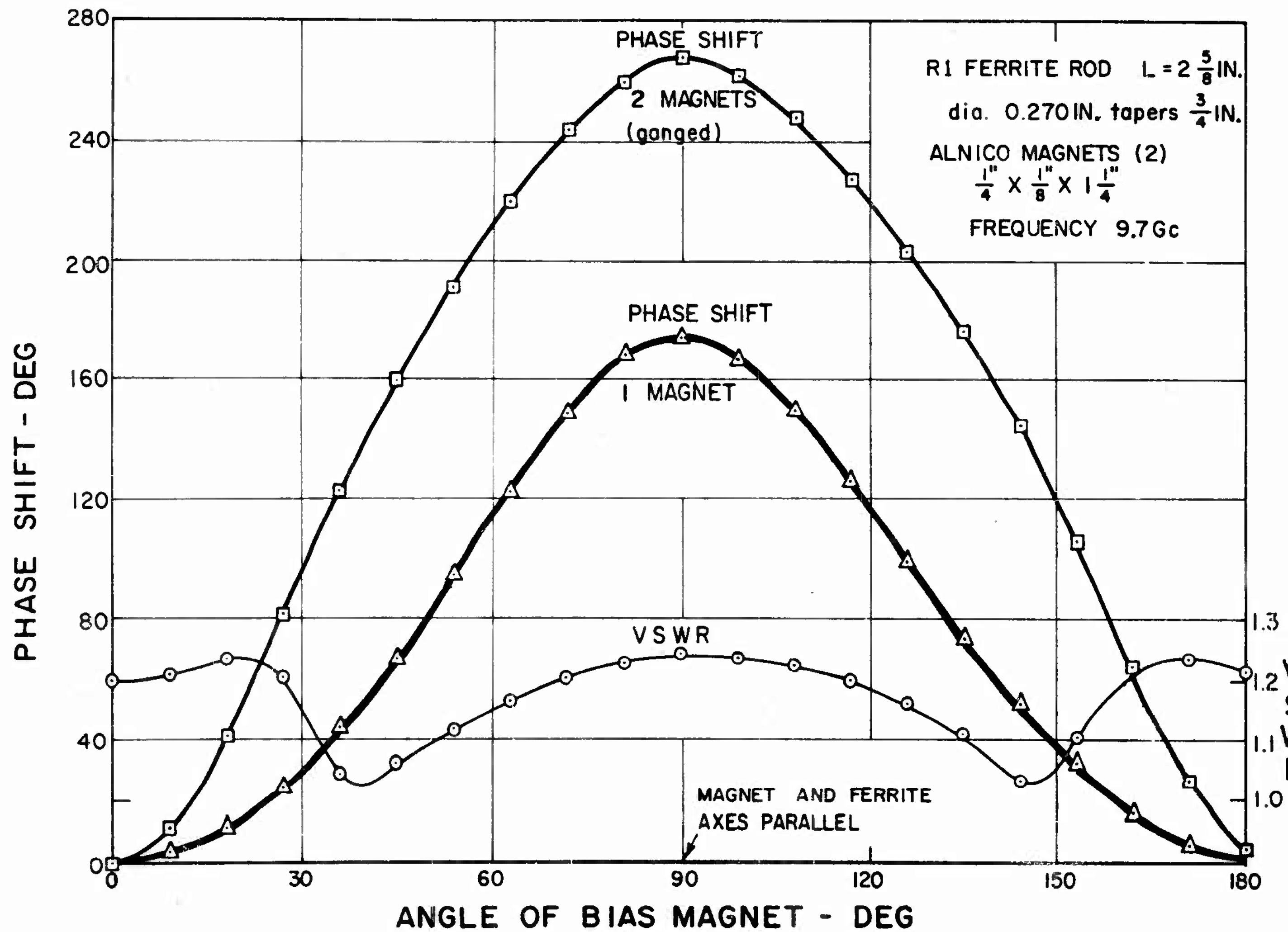

Figure 6. Phase shift and input VSWR versus angle of rotation of magnets used with magneto-mechanical phase modulator.

As seen in figure 6, when the biasing magnets were oriented perpendicular to the axis of the ferrite rod, little or no phase shift of the microwave energy is obtained. However, when one of the magnets is rotated so that its axis is parallel to that of the ferrite rod, a reciprocal phase shift of more than 170 deg is obtained. If both magnets are ganged and aligned such that like poles are together (fig. 1c), a phase shift in excess of 260 deg is obtained. Larger magnitudes of phase shift may be obtained by increasing the strength of biasing permanent magnets, length of ferrite rod, and length of biasing magnet. The input VSWR of this phase modulator with the two permanent magnets properly aligned and ganged together is given by the curve at the bottom of the figure.

4. PHYSICAL DESCRIPTION

A photograph of the three rectangular waveguide phase modulators described herein is given in figure 7. The model on the left clearly shows the two 90-deg E-plane bends at the top, the 180-deg zero-radius bend at the bottom, and the low-current solenoid around the 1- by 1-in. waveguide section containing the two ferrite rods. The short distance between the input and output flanges can be observed.

The circulator reflection-type phase modulator is shown at the center of figure 7. The E-plane tee ferrite circulator (1 1/4 by 1 1/4 by 1 5/8 in.) with two standard waveguide flanges added is seen at the top, while the reflection-type ferrite phase modulator with its short low-current solenoid can be seen at the bottom. The distance between the input and output ports of this phase modulator assembly including the two flanges is about 1 1/2 in.

The magneto-mechanical phase modulator with two rotating permanent magnets inside the assembly housing is shown at the right in figure 7. This transmission-type of reciprocal phase modulator is 2 5/8 in. long. One end of the tapered ferrite rod and polyfoam dielectric support are clearly seen inside the rectangular waveguide section. The calibrated dial on the top and the vernier scale on the front control the position and setting of the permanent magnets through a simple gear reduction mechanism inside the assembly housing. Although the housing for prototype units can be fabricated from aluminum stock, for any given quantity, investment casting techniques could easily be employed with substantial savings in overall cost.

5. OTHER APPLICATIONS OF TECHNIQUE

Besides replacing relatively large and bulky mechanical phase shifters, the above techniques can also be used in the design of small absorption modulator-switches (ref 6). In fact, the same waveguide assemblies described in the preceding sections can be used to obtain this amplitude modulation. It is only necessary to replace the phase shift element with another ferrite rod according to the design techniques described in reference 6. Thus, either a compact phase modulator

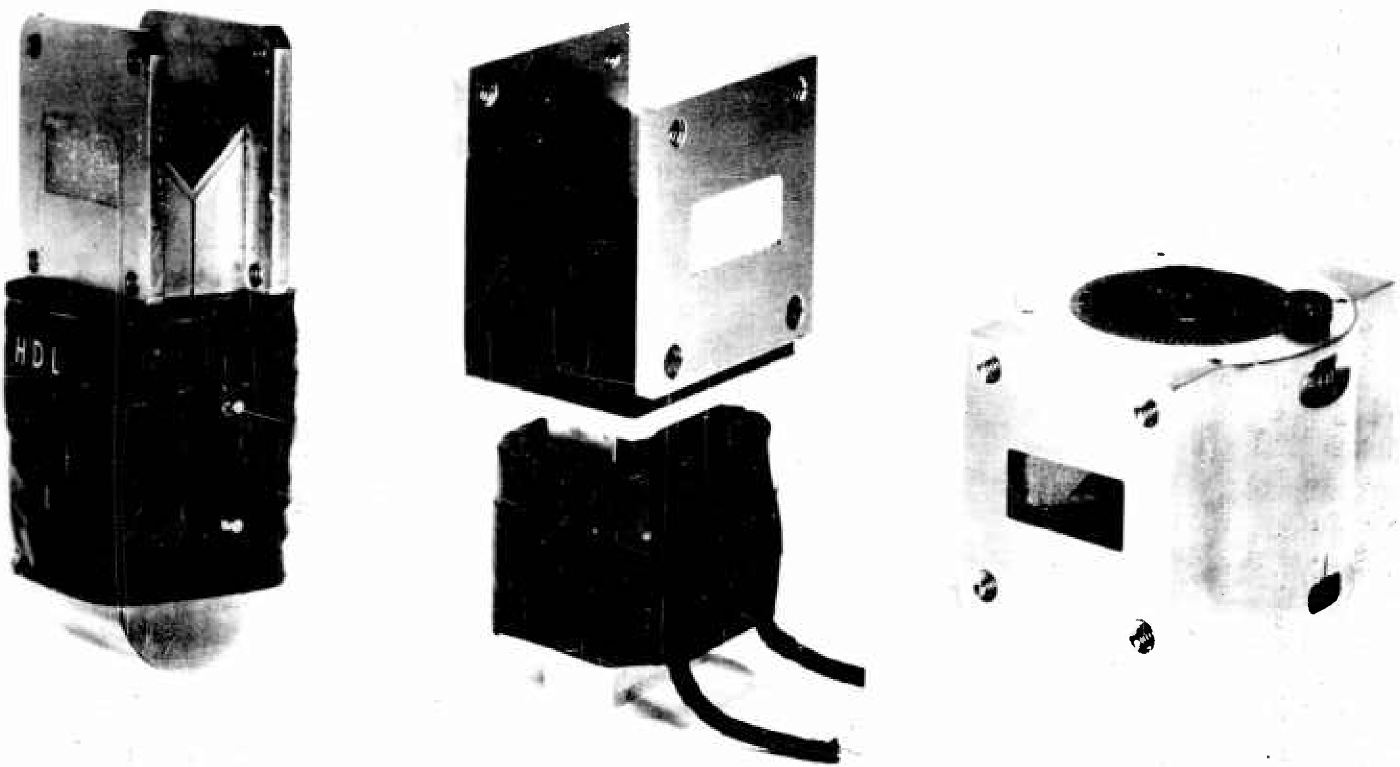

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Figure 7. Ferrite phase modulators designed in standard rectangular waveguide for 3-cm wavelength.

or an absorption modulator-switch can be made using the above techniques.

The phase modulators shown in figure 1a and 1b could also be used to design relatively small microwave scanning antennas. Because of the short distance between the input and output ports of these two types of phase modulators, the radiating elements could be kept very close together, thus simplifying the technique generally used to obtain rapid scanning of microwave antennas with low side-lobe levels.

6. CONCLUSION

Some unusual types of ferrite phase modulators, designed in standard rectangular waveguide operating in their fundamental TE_{01} mode, have been described. These low-field devices are characterized by small amplitude modulation and insertion loss, large phase shifts per unit length, and a nearly matched input impedance for all values of applied magnetic field. They are also capable of operating at rf power levels up to 25 w average and 5 kw peak. The results of this developmental effort haveyielded practical ferrite phase shifter designs which can be useful in the laboratory, as well as in modern radar systems.

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TR-1189, 30 December 1963, 6 pp text, 7 illus. DA Proj. 1P523801A300, AMCMS Code 5522.11.62400, HDL Proj 26300, UNCLASSIFIED Report

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